Insights on the dynamical history of the Fomalhaut system

Investigating the Fomalhaut c hypothesis


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30 years of Beta Pic and Debris disks studies
The Fomalhaut system
An eccentric outer belt

Offseted and eccentric Kuiper-belt with $e \sim 0.1$.

Presence of a belt-shaping massive body with $e \sim 0.1$ expected:
- $m \sim 3M_{\text{Jup}}$ (Chiang et al. 2009)
- Neptune-Saturn mass (Quillen 2006)

Combined HST (optical) and ALMA (850 microns) observations (Kalas et al. 2005; Boley et al. 2012).

Herschel/PACS observation at 70 microns
THE FOMALHAUT SYSTEM
FOMALHAUT B, NEAR THE BELT INNER EDGE

A CONTROVERSIAL STATUS

- Observed at visible wavelengths, but undetected in IR
  (Kalas et al. 2008; Marengo et al. 2009; Janson et al. 2012).

- Planetary body surrounded by dust? (Kennedy & Wyatt 2011; Kenyon et al. 2014)
  or a planetary ring system? (Kalas et al. 2008)

- Recent photometric studies: no more than Earth or Super-Earth sized
  (Janson et al. 2012; Galicher et al. 2013).
The Fomalhaut System

Fomalhaut b

Orbital Fitting (Kalas et al. 2013; Beust et al. 2014)

- Peak values: $a_b \sim 110 - 120$ AU & $e_b \sim 0.92 - 0.94$.
- 95% level of confidence:
  - $a_b \sim 81 - 415$ AU & $e_b \sim 0.69 - 0.98$.
- Belt-crossing.
- Nearly coplanar and close to apsidal alignment with the belt.

Dynamical analysis:

Fom b is

- a low-mass object,
- not responsible for the shape of the outer belt.

The first suspect is not the culprit here!
**The Fomalhaut System**

*Investigating the Fomalhaut c hypothesis (Faramaz et al. 2014, arXiv:1409.6868)*

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**Clues for an unseen massive Fom c.**

Stability?

- Highly unstable configuration (dynamical lifetime ≪ age of the system, 440 Myr).
- Fom b recently set on its orbit.

How? Why so late?

A dynamical scenario involving Fom c in the generation of Fom b-like orbits:

- shows that Fom b can be naturally put on its present-day orbit via perturbations by Fom c.
- can explain why it occurs so late and makes it likely for us to witness.
The key mechanism
Mean-motion resonances with an 0.1 eccentric Fom c

Example of Fom b progenitor originally trapped in 5:2 MMR on a low-eccentricity orbit with a 3 $M_{\text{Jup}}$
Fom c: $a_{b,0} \sim 58$ AU and $e_{b,0} \leq 0.05$

- Increase of eccentricity $\rightarrow$ crossing of the chaotic zone.
- Scattering event in the chaotic zone $\rightarrow$ Fom b-like orbit?
- MMRs delay scattering events.
  The delay depends on the mass of Fom c:
  - Jupiter mass Fom c $\rightarrow$ delay of several Myr.
  - Saturn-Neptune mass Fom c $\rightarrow$ delay of several 100 Myr.
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Eccentricity increase

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**THE KEY MECHANISM**

**Mean-motion resonances with an 0.1 eccentric Fom c**

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Crossing the orbit of Fom c

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A 2-step scenario?
A first summary

1. MMR with an eccentric Fom c
2. Scattering event in the chaotic zone.

First conclusions
A Saturn-Neptune mass Fom c with eccentricity 0.1:

- leads to the production of Fom b-like orbits, with a delay of several 100 Myr, via the 5:2 MMR.
- is compatible with the shaping of the outer belt.
- is compatible with the survival of the present transient configuration for $\sim 10$ Myr.
A surprising feature
Orientation of Fom b-like orbits originating from the 5:2 MMRs

Clear tendency for apsidal alignment and coplanarity.
Step 2: close encounter with Fom c

Before encounter:
- $a$ of the MMR
- $e$ allowed by the MMR.

Conservation of the Tisserand parameter links $(a, e)$ and $(a', e')$.

After encounter:
- $a' = 81 - 415$ AU (95% level of confidence for Fom b, Beust et al. 2014)
- $e' < 0.69 \Rightarrow$ Additional increase required

Step 3: secular evolution with an eccentric Fom c

Secular evolution permits $e_b > 0.69$ when orbits are apsidally aligned.
A 3-STEP PROCESS

Summary

3 Successive interactions with the eccentric Fom c:

- Step 1: MMR
- Step 2: Close-encounter
- Step 3: Secular interaction
## Conclusion

### A Possible Dynamical History for the Fomalhaut System

- A yet undetected eccentric Saturn-Neptune size Fom c.
- Fom b originates from an inner MMR with Fom c.
- Fom b was set recently on its current orbit by Fom c via a 3-step process.

### Producing Fom b-like Orbits is a Robust Process

Low mass material + massive eccentric planet:

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<tr>
<th>MMR</th>
<th>close encounter</th>
<th>secular evolution</th>
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<td>⇒ Fom b like orbits - Cometary activity?</td>
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- A 0.1 eccentric perturber naturally produces such orbits in a robust manner.
- The production of these orbits can be delayed on timescales > 100 Myr thanks to MMRs.

Faramaz et al., in prep:

- Link with inner belts in Fomalhaut? (Lebreton et al. 2013)
- Link with exozodis? (Absil et al. 2013; Ertel et al. 2014, 12 to 30% of stars)
Références